(01-017) - Modification to Remove the Anomaly of the Earned Value Analysis

Bettemir, Onder Halis [1]

[1] Inonu University

In this study, schedule performance index is modified by introducing the workmanship requirements of the activities to the schedule performance computations. The modification entails definitions of workmanship requirements of the activities. The proposed approach is examined on two hypothetical projects. The first project is a high rise construction project and the latter is a multi-span bridge construction. Durations and workmanship requirements are assigned for each activity then the construction process is simulated by randomly generated numbers which may delay or fasten the execution of the activities. The network is scheduled by critical path method and the actual start and finish times of the activities are computed according to the activity durations. Schedule performance indexes of the examined projects are computed for each day of the construction by implementing the present approach and the proposed modification. The modification reduced the abrupt changes and removed the anomalies. The modification might help the project managers to apply more robust and effective control on the construction duration.

Keywords: schedule performance index; earned value; scheduling; project management

Modificación para eliminar la anomalía del análisis del valor Ganado

El índice de cumplimiento del calendario se modifica introduciendo los requisitos de mano de obra de las actividades en los cálculos del cumplimiento del calendario. La modificación implica definiciones de los requisitos de mano de obra de las actividades. El enfoque propuesto se examina en dos proyectos hipotéticos. El primer proyecto es un proyecto de construcción de gran altura y el segundo es una construcción de puente de varios tramos. Se asignan duraciones y requisitos de mano de obra para cada actividad y luego el proceso de construcción se simula mediante números generados aleatoriamente que pueden retrasar o acelerar la ejecución de las actividades. La red se programa mediante el método de ruta crítica y los tiempos reales de inicio y finalización de las actividades se calculan de acuerdo con la duración de las actividades. Los índices de desempeño del cronograma de los proyectos examinados se calculan para cada día de la construcción implementando el enfoque actual y la modificación propuesta. La modificación redujo los cambios abruptos y eliminó las anomalías. La modificación podría ayudar a los directores de proyecto a aplicar un control más sólido y eficaz sobre la duración de la construcción.

Palabras clave: índice de rendimiento del cronograma; valor ganado; programación; gestión de proyectos

Correspondencia: Önder Halis Bettemir, onder.bettemir@inonu.edu.tr

1. Introduction

Implementation of robust control on the construction schedule is important since delay of a construction has many adverse consequences. Liquidated damages, cost overruns, and stress on the stakeholders of the project can be a few of them (Bettemir and Bulak, 2022). Therefore, discernment of a probable delay of the construction within the construction process is significantly important for project managers. The most widely used method to control construction schedule is the Earned Value Analysis (EVA) with the utilization of schedule performance index. Therefore in practice and in the literature EVA is implemented frequently.

Bhosekar and Vyas (2012) compared MS Project 2007, Primavera P6, and the developed software to examine Planned Value (PV), Actual Value (AV), Earned Value (EV), Cost Variance (CV), Schedule Variance with respect to time SV(t), and CPI indexes. A guest house construction is used for a case study and the aforementioned indexes are compared. The comparison revealed that the three examined software provide the same output. Bryde et al. (2018) mentioned some implementations of EVA including $1.13 billion airport construction where the project managers applied significant attention not to reduce the SPI below 0.8 to finish the project on time.

Vargas (2003) conducted a case study on a heavy construction company having $200 million yearly turnover. Three professionals of the company are interviewed. The responses demonstrated that EVA is a powerful tool and provides a favourable cost-benefit ratio if the scope of the project is defined clearly. Waris et al. (2012) examined the cost and schedule performance of up-gradation of a highway in Malaysia by EVA. The implemented method contributed project success. Bagherpour et al. (2010) implemented EVA to control the production processes by considering the time and cost of the manufacturing. Lukas (2008) suggests implementation of EVA when the project maturity level is 3 or higher. Main reasons for unsuccessful implementation of EVA are listed as incomplete Work Breakdown Structure (WBS) and project requirements, not integrating the WBS, schedule and budget. Acebes et al. (2015) developed a cost and schedule control approach with Monte Carlo Simulation to take the uncertainties into account. The model requires the entrance of the parameters of the probability distributions of the cost and duration of the construction activities. The probabilities of cost overruns and delays are computed. Bettemir (2020) estimated the uncertainties of the schedule by Monte Carlo Simulation, PERT and Modified PERT.

Most of the project managers implement EVA because of the performance progress demands of the external clients (Gershon, 2013). Project managers should be persuaded on the benefits of the EVA to implement it willingly. Almeida et al. (2021) examined fixed formula method by utilizing 0%, 10%, 25%, 50%, 75%, and 100% completion rates for the construction phases of the activities. The argument of the study is that the project progress measurements are not accurately executed because of the congestions on the construction site. The 50/50 rule gives the most proper results among the examined fixed formula rules. Projects with high Budget at Completion (BAC) and shorter durations are vulnerable to errors. Noori et al. (2008) applied fuzzy logic to EVA in order to model the uncertainties. Zohoori et al. (2019) implemented EVA for cost and time control of manufacturing of hydraulic lift and barriers. Fuzzy logic is utilized in order to model the uncertainties of the activity durations and costs. Zhong and Wang (2011) proposed assigning weights to the activities by considering their total float durations. The weighting algorithm gives more priority to the critical activities. Kwak and Anbari (2012) examined and assess the implementation of EVA by NASA projects. The authors recommended utilizing EVA for the projects which also have less than $20 million budget. The application of EVA is also suggested for the fixed-price projects. Valle and Soares (2006) examined the implementation of EVA on an amusement park project with $5 million budget and 10 months duration. The project is finished on time and within budget with EVA cost and duration control technique. Cioffi (2006) proposed a new notation for the EVA rather than the notation proposed by PMI. The algebraic notation of the parameters is expected to ease the utilization of EVA. Kim (2014) proposed implementing dynamic control thresholds for the budget and cost overruns. The threshold values are adjusted according to the percentage of completion of the project where the threshold values are higher in the beginning. Christensen (1998) discussed the costs and benefits of the implementation of EVA. The cost of the implementation can be reduced by eliminating the unnecessary activities. Howes (2000) investigated possible anomalies of EVA and proposed work package method (WPM) which treats similar activities together. The proposed method makes cost and schedule evaluations by considering the activities in the same work package. Liu and Jiang (2020) criticized EVA as it is based on the project schedule and budget which may change during the construction with scope changes. Moreover, quality is not considered at the present state of EVA.

EVA is an efficient method to control cost and time. Therefore, the method is implemented widely by the project managers and the researchers search for possible improvements of it. During the implementation of EVA, author noticed that EVA contains an anomaly and subjected to abrupt changes in Schedule Performance Index when expensive activities are delayed or finished earlier. In this study, the mentioned anomaly is illustrated by case studies and then modifications to reduce the anomaly are discussed. The remainder of the paper provides the computational details of the EVA in the methodology part, and then the anomaly is illustrated in the case study part. The possible modifications are also discussed in the case study part. The findings of the study are presented in the discussion of results part and finally the study is concluded.

2. Methodology

Moder et al. (1983) presented the computational details of the earned value analysis which were based on the Budgeted Cost of Work Scheduled (BCWS), Budgeted Cost of Work Performed (BCWP), and the Actual Cost of Work Performed (ACWP) indexes. Schedule Performance Index (SPI) is computed as given in Eq. 1.

$$SPI = \frac{BCWP}{BCWS} \tag{1}$$

CPI is computed by considering ACWP and BCWP. Computation of CPI is given in Eq. 2.

$$CPI = \frac{BCWP}{ACWP} \tag{2}$$

Composite Index (CI) is the weighted sum of SPI and Cost Performance Index (CPI). CI is computed by Eq. 3 (Christensen et al., 1992).

$$CI = W_1 * SPI + W_2 * CPI \tag{3}$$

In Eq. 3 the weights are assigned by the project manager according to the importance of the schedule and cost. CI index becomes a project success factor which depends on the achievement of the time and budget goals. In addition to the mentioned metrics three more metrics are defined. Planned Value (PV) is equal to the budgeted cost of the work scheduled from the commencement of the project until the time under consideration. Earned Value (EV) is the budgeted cost of work performed from the commencement of the project until the time under consideration. Actual Cost (AC) is the actual cost of work performed from the commencement of the project until the time under consideration. Cost Variance (CV) and Schedule Variance (SV) are computed as given in Eq. 4 and 5.

$$CV = EV - AC \tag{4}$$

$$SV = EV - PV \tag{5}$$

Negative CV and SV imply unfavorable conditions. The project performance at the end can be estimated based on the Budget at Completion (BAC), EV, and AC. To Complete Performance Index (TCPI) is computed as given in Eq. 6.

$$TCPI = \frac{BAC - EV}{BAC - AC} \tag{6}$$

The schedule performance indexes obtained by the literature review are cost based and may provide biased results when an expensive activity is delayed or ahead of time. Aforementioned situation can cause adverse consequences and disagreement between the project stakeholders during the execution of the project. In this study, three modifications are proposed for the SPI computation to diminish the aforementioned anomaly.

2.1 First Modification for SPI

The first modification computes the SPI index without considering the budget of the activities. This situation assumes that all of the activities have unit budgeted cost. The scheduled activity execution rate is illustrated in Eq. 7.

$$SAP_{i,j} = \frac{1}{D_j^S} * \delta_{i,j}^S \tag{7}$$

$SAP_{i,j}$ refers to the Scheduled Activity Performance of the j^{th} activity at the i^{th} day. DS_j is the scheduled duration of the j^{th} activity, $\delta S_{i,j}$ becomes 1 if the j^{th} activity is scheduled to be executed at the i^{th} day, otherwise it is 0. Actual activity execution rates are illustrated in Eq. 8.

$$AAP_{i,j} = \frac{1}{D_j^A} * \delta_{i,j}^A \tag{8}$$

$AAP_{i,j}$ refers to the Actual Activity Performance of the j^{th} activity at the i^{th} day. DA_j is the actual duration of the j^{th} activity, $\delta A_{i,j}$ becomes 1 if the j^{th} activity is executed at the i^{th} day, otherwise it is 0. Scheduled Project Performance (SPP) and the Actual Project Performance (APP) indexes are computed as given in Eq. 9 and 10 respectively.

$$SPP_i = \sum_{j=1}^{n} SAP_{i,j} \tag{9}$$

$$APP_i = \sum_{j=1}^{n} AAP_{i,j} \tag{10}$$

In Eq. 9 and 10 *n* is the number of activity of the project. The first modification of SPI is computed as given in Eq. 11.

$$SPI_i^{M1} = \frac{APP_i}{SPP_i} \tag{11}$$

2.2 Second Modification for SPI

Daily Activity Performance (DAP) index is computed for each activity as given in Eq. 12.

$$DAP_{i,j} = \frac{D_j^S}{D_j^A} * \delta_{i,j}^A \tag{12}$$

Daily Project Performance (DPP) and activity execution numbers for the i^{th} day of the construction is computed as given in Eq. 13 and 14.

$$DPP_i = \sum_{j=1}^{n} DAP_{i,j} \tag{13}$$

$$\Delta_i^A = \sum_{j=1}^{n} \delta_{i,j}^A \tag{14}$$

In Eq. 14 Δ_i^A represents the total of the number of construction activities executed between the first and the i^{th} day of the construction. Second modification of SPI index is computed as given in Eq. 15.

$$SPI_i^{M2} = \frac{\sum_{k=1}^{i} DPP_k}{\sum_{k=1}^{i} \Delta_k^A} \tag{15}$$

2.3 Third Modification for SPI

The third modification assigns weight to the activities by considering the workmanship requirements of the activities. Daily Workmanship Performance (DWP) of the activities for each day is computed by Eq. 16.

$$DWP_{i,j} = \frac{BWR_j}{D_j^A} * \delta_{i,j}^A \tag{16}$$

In Eq. 16, BWR_j is the budgeted workmanship requirement of the j^{th} activity which represents the estimated man.day requirement of the corresponding activity. The third modified SPI index is computed as given in Eq. 17.

$$SPI_i^{M3} = \frac{\sum_{k=1}^{i}\sum_{j=1}^{n} DWP_{k,j}}{\sum_{k=1}^{i}\sum_{j=1}^{n}\left(CS_j * \delta_{i,j}^{A}\right)} \quad (17)$$

In Eq. 17 CS_j is the crew size of the j^{th} activity.

3. Case Studies

In this study, SPI is examined by two case studies. The anomaly of EVA is examined on two hypothetical construction projects which consist of a building construction and a multi-span bridge construction.

3.1 Case Study 1

In this case study project performance of a building construction consisting of one basement and five upper floors is examined. The budgeted cost and the scheduled start and end times of the activities are listed in Table 1. The last column represents the crew size of the corresponding activity. The total workmanship is obtained by multiplying the crew size with the duration of the activity.

Table 1. Budgeted Cost and Schedule of the first hypothetic project

Activities	Duration	Start	Finish	Cost (€)	Crew Size
Excavation	7	0	7	22500	2
Foundation Formwork	2	7	9	31802	3
Foundation Reinforcement	8	7	15	621600	6
Foundation Concreting	1	15	16	301400	4
Basement Formwork	10	21	31	17500	5
Basement Reinforcement	10	21	31	327000	6
Basement Concreting	1	31	32	181400	4
Floor 1 Formwork	10	37	47	111840	5
Floor 1 Reinforcement	10	37	47	327000	6
Floor 1 Concreting	1	47	48	181400	1
Floor 2 Formwork	10	53	63	111840	4
Floor 2 Reinforcement	10	53	63	327000	5
Floor 2 Concreting	1	63	64	181400	6
Floor 3 Formwork	10	69	79	111840	1
Floor 3 Reinforcement	10	69	79	327000	4
Floor 3 Concreting	1	79	80	181400	5
Floor 4 Formwork	10	85	95	111840	6
Floor 4 Reinforcement	10	85	95	327000	1
Floor 4 Concreting	1	95	96	181400	4
Floor 5 Formwork	10	101	111	111840	5
Floor 5 Reinforcement	10	101	111	327000	6
Floor 5 Concreting	1	111	112	181400	1
Floor 1 Masonry	8	80	88	56000	5
Floor 2 Masonry	8	88	96	56000	5
Floor 3 Masonry	8	96	104	56000	5
Floor 4 Masonry	8	104	112	56000	5
Floor 5 Masonry	8	112	120	56000	5
Basement MEP	3	112	115	6650	3

Floor 1 MEP	3	115	118	6650	3
Floor 2 MEP	3	118	121	6650	3
Floor 3 MEP	3	121	124	6650	3
Floor 4 MEP	3	124	127	6650	3
Floor 5 MEP	3	127	130	6650	3
Basement Plastering	7	118	125	21250	5
Floor 1 Plastering	7	125	132	21250	5
Floor 2 Plastering	7	132	139	21250	5
Floor 3 Plastering	7	139	146	21250	5
Floor 4 Plastering	7	146	153	21250	5
Floor 5 Plastering	7	153	160	21250	5
Floor 1 Floor Covering	5	132	137	109000	4
Floor 2 Floor Covering	5	137	142	109000	4
Floor 3 Floor Covering	5	142	147	109000	4
Floor 4 Floor Covering	5	147	152	109000	4
Floor 5 Floor Covering	5	152	157	109000	4
Basement Painting	4	142	146	16800	4
Floor 1 Painting	4	146	150	16800	4
Floor 2 Painting	4	150	154	16800	4
Floor 3 Painting	4	154	158	16800	4
Floor 4 Painting	4	158	162	16800	4
Floor 5 Painting	4	162	166	16800	4

The actual schedule of the hypothetical project is illustrated in Table 2. The crew size is assumed to be the same with the initial schedule.

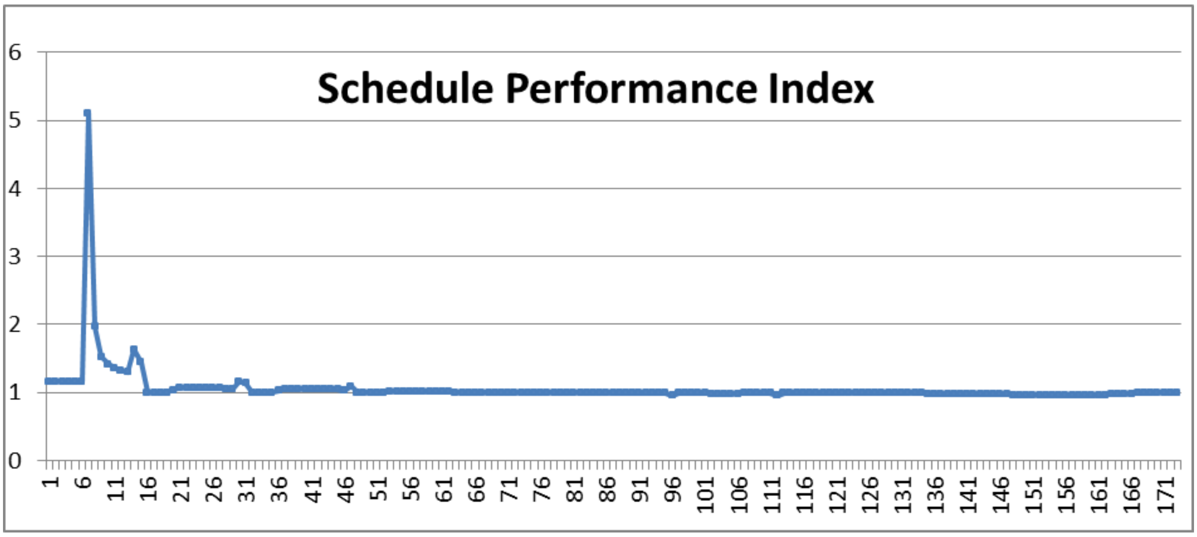
Table 2. Actual Schedule of the hypothetic project

Activities	Duration	Start	Finish
Excavation	6	0	6
Foundation Formwork	2	6	8
Foundation Reinforcement	7	6	13
Foundation Concreting	1	13	14
Basement Formwork	9	19	28
Basement Reinforcement	10	19	29
Basement Concreting	1	29	30
Floor 1 Formwork	11	35	46
Floor 1 Reinforcement	10	35	45
Floor 1 Concreting	1	46	47
Floor 2 Formwork	9	52	61
Floor 2 Reinforcement	11	52	63
Floor 2 Concreting	1	63	64
Floor 3 Formwork	10	69	79
Floor 3 Reinforcement	10	69	79
Floor 3 Concreting	1	79	80
Floor 4 Formwork	10	85	95
Floor 4 Reinforcement	11	85	96
Floor 4 Concreting	1	96	97
Floor 5 Formwork	9	102	111
Floor 5 Reinforcement	10	102	112
Floor 5 Concreting	1	112	113
Floor 1 Masonry	10	80	90
Floor 2 Masonry	9	90	99
Floor 3 Masonry	8	99	107
Floor 4 Masonry	8	107	115
Floor 5 Masonry	7	115	122
Foundation MEP	4	115	119

Floor 1 MEP	3	119	122
Floor 2 MEP	3	122	125
Floor 3 MEP	3	125	128
Floor 4 MEP	3	128	131
Floor 5 MEP	3	131	134
Foundation Plastering	8	122	130
Floor 1 Plastering	7	130	137
Floor 2 Plastering	7	137	144
Floor 3 Plastering	7	144	151
Floor 4 Plastering	7	151	158
Floor 5 Plastering	6	158	164
Floor 1 Floor Covering	6	137	143
Floor 2 Floor Covering	5	143	148
Floor 3 Floor Covering	5	148	153
Floor 4 Floor Covering	5	159	164
Floor 5 Floor Covering	5	164	169
Foundation Painting	5	148	153
Floor 1 Painting	4	153	157
Floor 2 Painting	4	157	161
Floor 3 Painting	4	161	165
Floor 4 Painting	4	165	169
Floor 5 Painting	4	169	173

Each of the excavation, reinforcement and formwork for the foundation tasks are completed 1 day earlier than the scheduled duration. Durations of the formwork and reinforcement tasks of the upper floors deviate ± 1 day. The construction can be considered within schedule and excessive deviations in the SPI metric are not expected. The SPI metric of the construction is given in Figure 1.

Figure 1: Daily SPI values of the hypothetical project 1

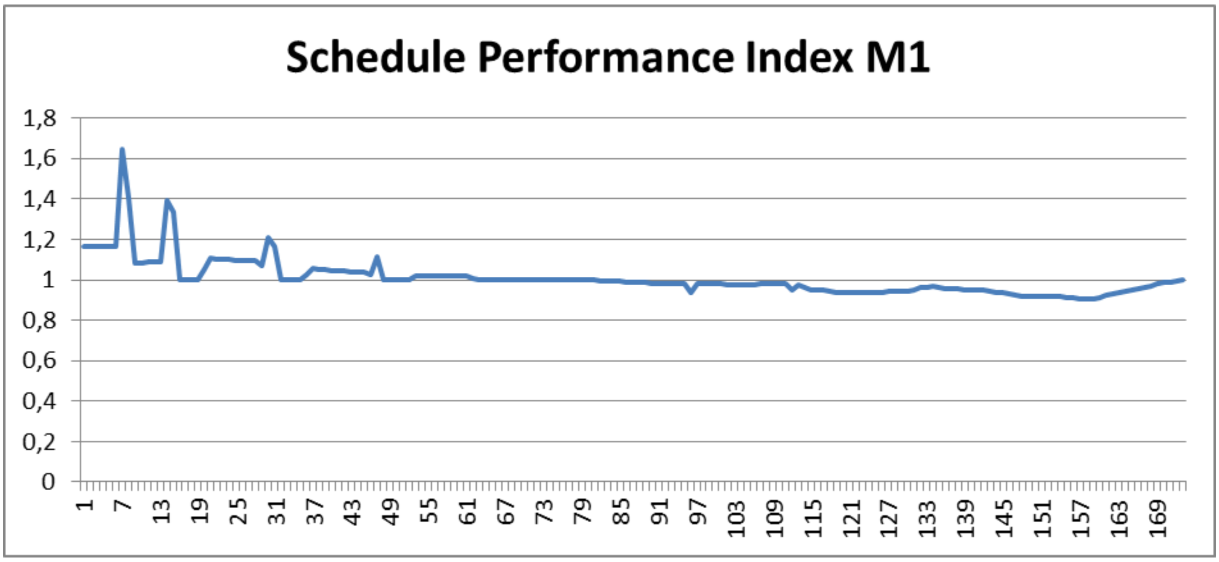


At the 7th day of the construction SPI is computed as 5.10, which indicates that the construction is five times faster than the schedule. The abrupt increase occurred due to the 1 day early finish of the low cost excavation task and 1 day early commencement of the expensive reinforcement task. If the excavation task is finished 1 day later than the scheduled duration, the SPI index would be 0.2. In the beginning of the construction it is known that the SPI index provides extreme values for being slightly late or early. However, at the final stages of the construction SPI index provides extremely low responses for being late or early. To illustrate, at a certain phase of the construction if the earned value is €100 million and a scheduled €1 million activity has been delayed by 10 days, the SPI index would reduce to 0.99 probably which will not activate any threshold. Kim (2015) also mentioned this situation and proposed adaptive thresholds during the construction since the SPI becomes unresponsive at the late phase of the construction. To conclude, in the beginning of the construction a small mistake is harshly penalized, while a large mistake at the final phase of the construction is slightly penalized. A delay in the beginning of the construction can be compensated easily but a delay at the final phase of the construction cannot be compensated without significant expense and stress.

In Figure 1, SPI index has high rises and falls between the 14th and 30th days. At the mentioned days the construction schedule has not been delayed nor crashed. An expansive construction task, concreting, is executed at the aforementioned days, which affects the SPI value significantly. The rise in the SPI index implies being a head of schedule; however the construction is not a head of the schedule only a head in terms of progress payments since an expensive construction activity is executed earlier than the scheduled date.

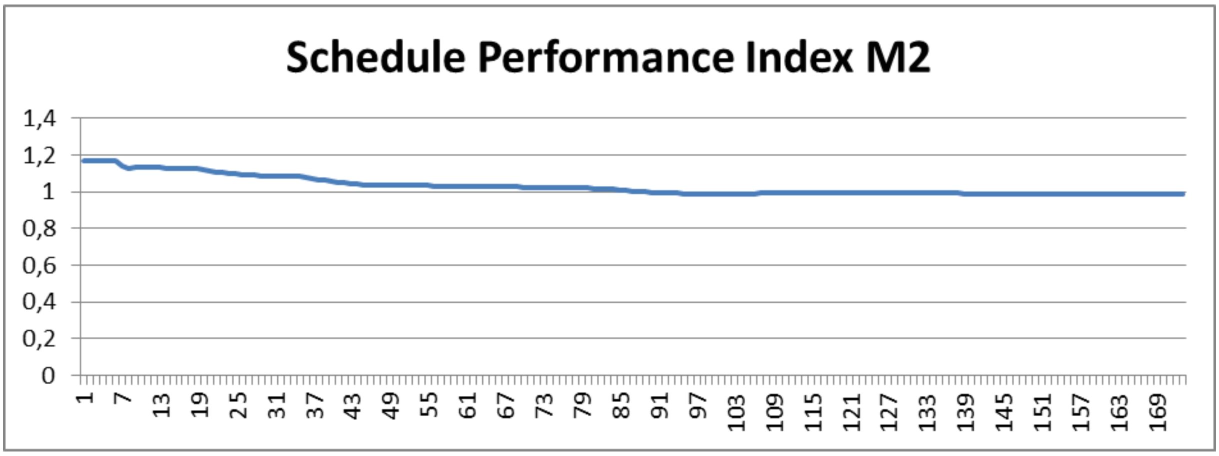
The anomaly of SPI index is tried to be eliminated by assigning equal weights to all of the activities, instead of using budgeted cost. The same construction is analyzed by implementing the first modification for the SPI computations. The obtained graph is presented in Figure 2. This index is normalized that it always converges to 1 at the end of the construction. When the index values are examined it is seen that in the beginning the response of the index is also higher but not as much as the present approach. Initially the index starts with the value 1.16 since the excavation activity is executed faster than it is scheduled. The index increases to 1.64 since formwork and reinforcement of the foundation had started earlier than the scheduled date. The construction continues with the expected speed and the index reduces to 1.08 at the 9th day, since the formwork task both finishes at the scheduled and the actual case.

Figure 2: Daily values of the modified SPI 1 of the hypothetical project 1.



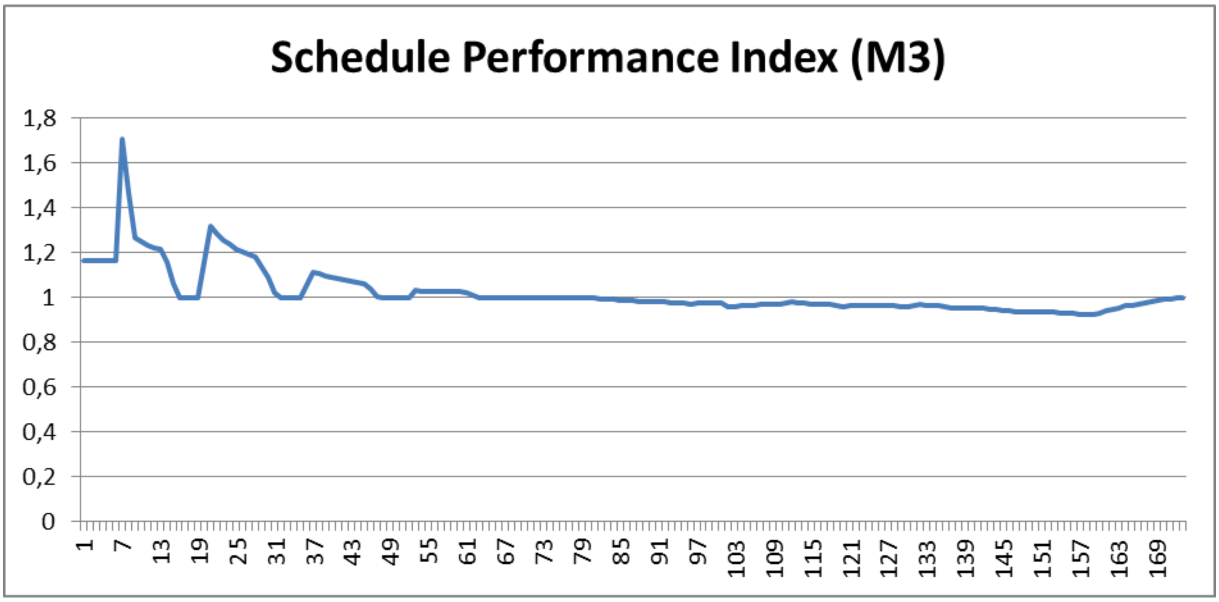
Delay of the construction is warned with higher response when the cost of the delayed activity is low. The modified SPI values are lower than the present SPI values at the later phases of the construction. The modification reduced the anomalies while did not removed the saturation of the index at the later phases of the construction.

Figure 3: Daily values of the modified SPI 2 of the hypothetical project 1.



Moving average based SPI provides the most smoothed index in which there is not any sharp rises and falls during the construction. However, the construction is delayed at the later phases but the index gives only a slight warning. Saturation at the later phases of the construction is the drawback of the second modification.

Figure 4: Daily values of the modified SPI 3 of the hypothetical project 1.



The third modification assigns weights to the activities by considering their workmanship requirements. The modification reduced the fluctuations at important amount compared with the previous case. In addition to this, the warning at the later phase is adequate to take precaution. The activities consisting of more workmanship are more difficult and costly to crash when they are late. The proposed modification gives more priority to the activities with high workmanship demand.

3.2 Case Study 2

Second case study problem is a viaduct construction with 10 pier and 9 spans. The budgeted cost and schedule is given in Table 3.

Table 3. Budgeted Cost and Schedule of the second hypothetic project

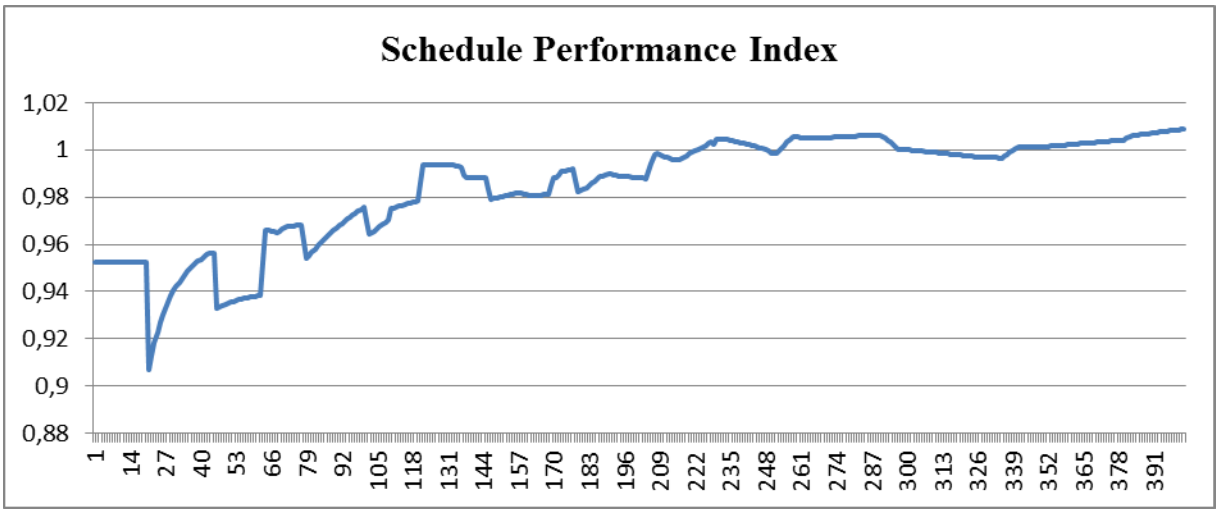
Activity	Duration	Start	Finish	Cost (€)	Crew Size
Excavation for Pier A	20	0	20	17000	5
Bore Pile for Pier A	25	20	45	23000	8
Construction of Pier A	17	45	62	30000	15
Construction of Beam AB	20	100	120	45000	10
Excavation for Pier B	23	20	43	19000	5
Bore Pile for Pier B	32	45	77	23000	8
Construction of Pier B	23	77	100	22000	15
Construction of Beam BC	23	145	168	40000	10
Excavation for Pier C	25	43	68	21900	5
Bore Pile for Pier C	33	77	110	28600	8
Construction of Pier C	35	110	145	28800	15
Construction of Beam CD	27	177	204	57600	10
Excavation for Pier D	32	68	100	24500	5
Bore Pile for Pier D	28	110	138	29500	8
Construction of Pier D	32	145	177	24100	15
Construction of Beam DE	22	207	229	55200	10
Excavation for Pier E	33	100	133	27700	5
Bore Pile for Pier E	35	138	173	28700	8
Construction of Pier E	30	177	207	34100	15
Construction of Beam EF	31	230	261	47200	10
Excavation for Pier F	24	133	157	22400	5
Bore Pile for Pier F	22	173	195	26900	8
Construction of Pier F	23	207	230	35600	15
Construction of Beam FG	31	261	292	44400	10
Excavation for Pier G	24	157	181	27800	5
Bore Pile for Pier G	22	195	217	25400	8
Construction of Pier G	20	230	250	36800	15
Construction of Beam GH	31	292	323	54800	10
Excavation for Pier H	27	181	208	25100	5
Bore Pile for Pier H	29	217	246	25700	8
Construction of Pier H	34	250	284	33300	15
Construction of Beam HI	30	323	353	45800	10
Excavation for Pier I	22	208	230	28800	5
Bore Pile for Pier I	24	246	270	20100	8
Construction of Pier I	28	284	312	27900	15
Construction of Beam IJ	30	353	383	51200	10
Excavation for Pier J	22	230	252	28900	5
Bore Pile for Pier J	27	270	297	22700	8
Construction of Pier J	23	312	335	23100	15
Construction of Beam JK	24	383	407	54200	10

Table 4. Actual Schedule of the second hypothetic project

Activity	Duration	Start	Finish
Excavation for Pier A	21	0	21
Bore Pile for Pier A	25	21	46
Construction of Pier A	18	46	64
Construction of Beam AB	20	102	122
Excavation for Pier B	24	21	45
Bore Pile for Pier B	33	46	79
Construction of Pier B	23	79	102
Construction of Beam BC	23	147	170
Excavation for Pier C	27	45	72
Bore Pile for Pier C	30	79	109
Construction of Pier C	38	109	147
Construction of Beam CD	28	179	207
Excavation for Pier D	32	72	104
Bore Pile for Pier D	27	109	136
Construction of Pier D	32	147	179
Construction of Beam DE	21	207	228
Excavation for Pier E	33	104	137
Bore Pile for Pier E	34	137	171
Construction of Pier E	27	179	206
Construction of Beam EF	32	228	260
Excavation for Pier F	24	137	161
Bore Pile for Pier F	19	171	190
Construction of Pier F	21	206	227
Construction of Beam FG	30	260	290
Excavation for Pier G	26	161	187
Bore Pile for Pier G	25	190	215
Construction of Pier G	22	227	249
Construction of Beam GH	32	290	322
Excavation for Pier H	28	187	215
Bore Pile for Pier H	27	215	242
Construction of Pier H	37	249	286
Construction of Beam HI	30	322	352
Excavation for Pier I	20	215	235
Bore Pile for Pier I	24	242	266
Construction of Pier I	30	286	316
Construction of Beam IJ	28	352	380
Excavation for Pier J	23	235	258
Bore Pile for Pier J	24	266	290
Construction of Pier J	25	316	341
Construction of Beam JK	22	380	402

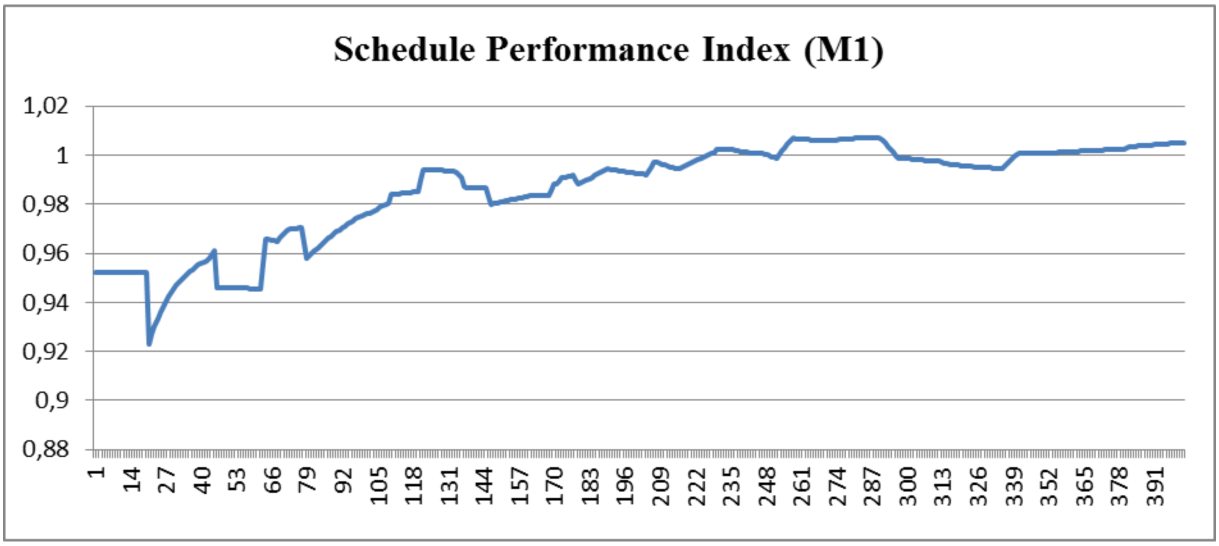
SPI is computed according to the present approach is given in Figure 5.

Figure 5: Daily SPI values of the hypothetical project 1.



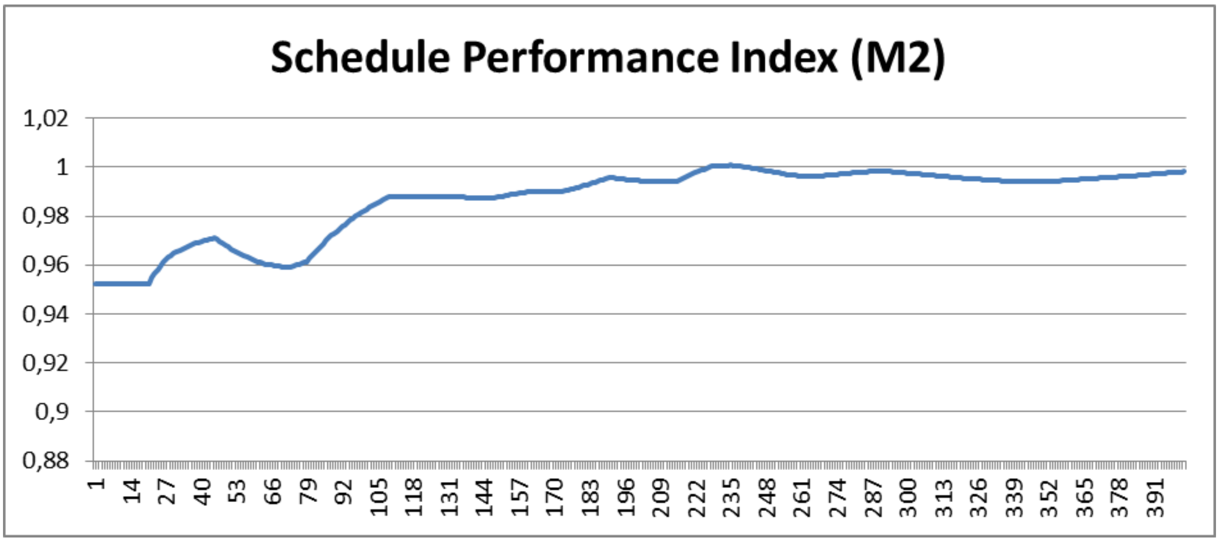
In the beginning the construction is behind the schedule because of the delayed excavation. The sharp decrease at the 21st day is because of the late start of more expensive Bore Pile activity. The amplitude of the rise and fall decreases as the index satisfies at the later stages of the construction.

Figure 6: Daily values of the modified SPI 1 of the hypothetical project 2.



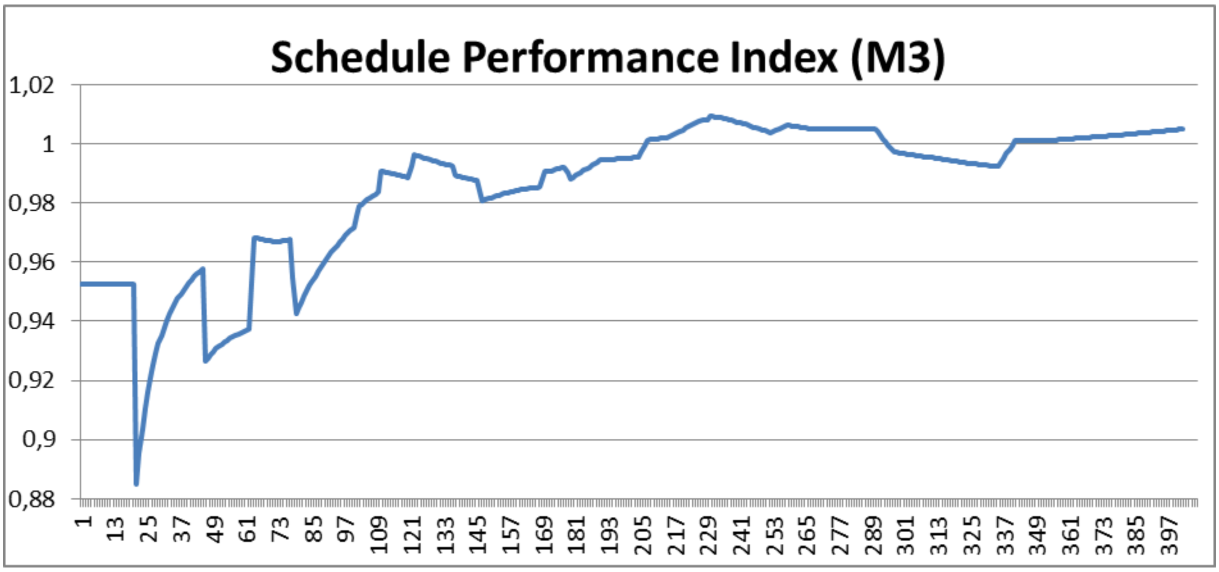
In Figure 6 the SPI of first modification is presented. The rises and falls are reduced compared with the original SPI values. Pattern of both indexes are similar but the modified index the amplitude is smaller. Figure 7 illustrates the second modification for the SPI index which is based on moving average. The index significantly smooths the fluctuations when compared with the Figure 5 and 6. The second modification has an anomaly that the construction is completed ahead of the schedule. However, the final SPI value is less that 1 which means construction is delayed.

Figure 7: Daily values of the modified SPI 2 of the hypothetical project 2.



Workmanship based SPI diagram is given in Figure 8. This index provides the most fluctuated SPI values. In this case study, the cost values of the activities are close to each other but the crew sizes of the activities deviate more. Therefore the workmanship based index become more sensitive to the early or late start of the activities with crowded construction crews.

Figure 8: Daily values of the modified SPI 3 of the hypothetical project 2.



4. Discussion of Results

In this study, anomalies and drawbacks of SPI is discussed by using two case study problems. SPI value provides the ratio of the earned progress payment to the predicted amount. Therefore, SPI value does not directly represent the situation of the construction with respect to schedule. The most problematic situation occurs when expensive activities are delayed or ahead of the schedule. The expensive but uncritical activities may be executed earlier to get their progress payments earlier and less expensive but difficult activities may be delayed. The SPI cannot detect such a case and it may provide gorgeous values for the project managers. In addition to this if an activity is ahead or behind the schedule in the early phases of the construction, the SPI gives significant response. However, the response dims if the same thing happens in the final phases of the construction. Ironically, the final phases of the construction are significantly critical since a mistake cannot be compensated easily and the SPI does not warn properly if the construction is behind the schedule.

This study attempts to eliminate the aforementioned drawbacks by modifying the SPI meyhod. In this study, three modifications are examined. The first modification gives same priority to the activities. This reduced the upper and lower bounds of the fluctuations which may prevent false alarms or rewards. However, the saturation problem of the SPI at the later phases could not be solved. Large projects may have hundreds of activities and delay of an activity at the final phases of the project may decrease the SPI in the order of one hundredth.

The second modification aims to reduce the fluctuations and provide smoother SPI curve without false warnings. The moving average based approach significantly reduced the fluctuations of the SPI index. The biased fluctuations are removed however; the index does not converge to 1 at the end of the construction. In the second case problem the construction is completed ahead of the schedule but the SPI is less than 1 which is controversy. The second index is the most vulnerable index to saturation.

The third modification assigns weights to the activities by considering their workmanship requirements. The difficulty of an activity is expected to be more relevant to its labor demand rather than its cost. The pattern of the SPI graph of the third modification is similar to the SPI graph of the present SPI method. The only differences are caused by the differences of cost and labor demands of the activities. The aforementioned anomalies about the SPI values can be observed in this index if there are significant differences between the labor demands of the activities. This modification cannot eliminate the saturation problem at the final phase of the construction.

5. Conclusion

The present SPI index has some anomalies if the costs of the activities deviate significantly. Moreover, the index saturates at the final phases of the construction. In this study, three modifications for the SPI index are examined to eliminate the aforementioned drawbacks. The modifications reduced the abrupt fluctuations which occur in the early phase of the construction. Especially the second modification provides smooth SPI graph compared with the other modifications. The saturation problem at the final phase of the construction could not be eliminated by the modifications. However, the final phase of the construction has significant importance since the possible delay cannot be compensated easily. Therefore, a proper warning metric which is also valid at the final phase of the construction should be developed as a future study.

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